# Protoplanets in the protoplanetary disc

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**Abstract**

This paper is an overview of the formation of planetary systems. We discuss the star formation with the X-mechanism. After that, we review the two main planet formation processes. At the end, we give a summary of planet-disc interaction with planet migration, which can cause the evolution of resonant orbits. These resonant orbits in the protoplanetary disc change when the disc disappears.
KEYWORDS: *planet formation, resonances, accretion disc, star formation*

## 1. Introduction

Nowadays more than a hundred exoplanets are known. Some of them have very strange orbits (high eccentricity, very small semimajor axis) and others are in resonance (e.g. 2:1). To explain these phenomena we have to understand the formation of these planets. However, the origin of planets and the origin of stars are related, we cannot understand planet formation without understanding star formation. The foremost question that we have to answer is, what kind of circumstances rule under star formation. The investigation of the planet formation mechanism is also an important question, as well as the investigation of the future of protoplanets.

## 2. Star formation in brief

Stars form in giant molecular clouds, like the Orion Nebula. First a globula evolves, which is 0.1 pc in diameter, the density of this core is $10^4$ molecule/cm$^3$ and the temperature is 10-100 K. These cores very often contain an IR source, which implies the existence of a star or protostar in the centre.

The globulas are spherical, but their collapses are not spherical. The cosmic radiation ionize the interstellar matter in the globula and the ions move around the local component of the galactic magnetic field. The ions collide with neutral atoms, so the globula begins to rotate around an axis. The rotating matter can

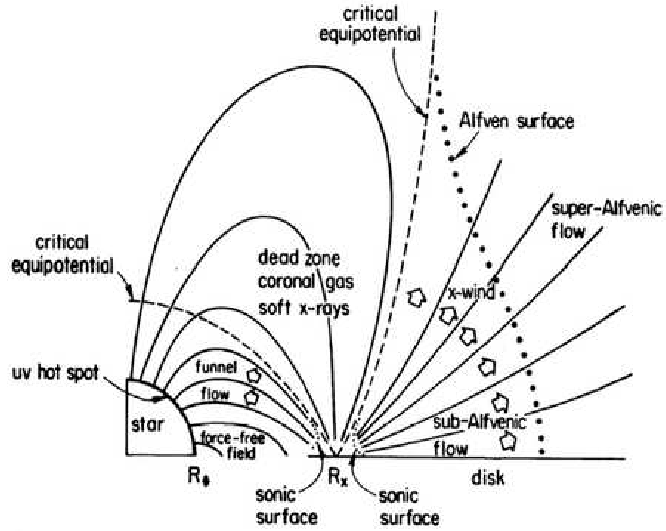


Figure 1: The X-mechanism Shu et al. (1994)

collapse along its axis, so an accretion disc grows up. The gas does not fall directly into the protostar, first it falls into the disc.

The disc does not extend to the protostar, due to the interaction of the protostellar magnetic field and the disc matter. The protostar ionizes the surface of the disc, thus the disc disturbs the magnetic field (Figure 1). At a radius ($R_X$) the magnetic field opens a gap between the star and the disc. Moreover, angular momentum flows from the protostar to the disc through the magnetic field, so a part of the disc matter is thrown out. This theoretical outflow is the so-called X-wind, which we see as a protostellar stellar wind (Shu et al., 1994). This mechanism unfortunately cannot exactly explain the observed jets in the protostellar systems, because the angle of the X-wind and the disc is relatively small, but the observed jets are perpendicular to the accretion discs.

| max/min density | 100:1 | 30:1 | 10:1 |
|---|---|---|---|
| M $[M_J]$ | 15 | 1.9 | 0.63 |
| $M_{Jeans}$ $[M_J]$ | 0.39 | 0.57 | 0.44 |
| R $[AU]$ | 1.0 | 0.61 | 0.35 |
| T $[K]$ | 97 | 103 | 104 |
| $E_T/E_{grav}$ | 0.03 | 0.44 | 1.0 |
| a $[AU]$ | 11.8 | 11.8 | 11.8 |
| e | 0.08 | 0.1 | 0.1 |

Table 1: Structure of a clump. In all the cases the clump mass is larger than the Jeans mass. The free-fall time is 1 year in all cases.The integration time was 345 years (Boss, 2002).

## 3. Planet formation in brief

### 3.1. The core collision mechanism

There are two different types of planet formation. The first one is the so-called core collision mechanism. In the accretion (or protoplanetary) disc the temperature is relatively low and the density is high, so heavier elements can condense. Since the disc temperature depends on the distance from the star, the high melting-point components (e.g. silicates) condense in the inner system. These cores collide with each other and sometimes they cohere creating larger and larger cores occasionally.

This is a slow process with timescale of $10^6$ years.We think that less massive planets are produced by this mechanism. Due to the interaction with the gas, the small particles spiral into the star very fast. For example the semimajor axis of a particle with 1 cm diameter will decrease 10 cm in each second.

### 3.2. Planet formation by disc instability

The gas flows in a protoplanetary disc are turbulent according to numerical simulations. Turbulence can be caused by viscosity of the gas and/or thermodynamical effects (Boss, 2002). Turbulence creates gravitationally unstable clumps on a timescale of 100-1000 years. These clumps are at least 5 AU away from the star and their mass is 0.5 or more Jupiter-mass. The structure of a typical clump is shown in Table 1.

One can see that this mechanism can produce giant planets. These planets perturb the disc strongly. This strong perturbation can even cause fragmentation of the disc. The fragmentation can cause the formation of some additional giant planets. We have to note, that the circumstances are more prosperous for clump creation at the beginning of the star formation, since the mass of the future star is still in the disc. But how does a system evolve after an early fragmentation?

## 4. Interaction between planets and the protoplanetary disc

The future of the protoplanets in the disc is strongly influenced by the disc. The planets interact with the disc, which cause angular momentum transport. Because of this transport, the semimajor axis of the planets decrease, the planets migrate toward the star (Lin & Papaloizou , 1986). The speed of the migration is proportional to the mass of the planet. The planet mass is also important because of another aspect. When the mass is greater than one Jupiter-mass, a gap opens in the disc around the planet (Ward , 1997). The migration across the gap is slow. Migration without gap is called type I migration, and with gap type II migration.

The disc-planet interaction helps to evolve resonant orbits in planetary systems. Some examples are shown in Table 2. There are 2:1 resonance in two of the systems. About the stability of them see Érdi & Pál (2003), and about the origin of this 2:1 resonance see Kley (2003).

A protoplanetary disc contains about 0.1 $M_\odot$ of matter at the main accretion phase. After the source of the falling matter runs out, the disc disappears slowly. The X-wind blows out one third of the disc mass, and just two third fall into the star. The fotoevaporation and stellar wind reduce it also, so at the end the disc disappears. This process takes about $10^6$-$10^7$ years. Because the mass inside a given radius around the star depends on the distance from the star and density distribution of the disc, the periods of the planets do not change in the same way during the disappearing. Moreover the disc disappears not simultaneously everywhere. When one of the resonant planets gets out of the disc, the other one is still in the disc and interacts with it, while the first one doesn't. So the existing resonances change.

## 5. Summary

The structure of planetary systems is strongly influenced by their original protoplanetary disc. Streams in the disc can produce giant planets. Interaction between the planets and the disc result type I or II migration, that can cause

| | Per [$d$] | M $sini$ [$M_J$] | a [$AU$] | e | $\omega$ | M |
|---|---|---|---|---|---|---|
| GJ 876 (2:1) | | | | | | 0.32 |
| c | 30.569 | 0.766 | 0.13 | 0.24 | 159 | |
| b | 60.128 | 2.403 | 0.21 | 0.04 | 163 | |
| HD 82943 (2:1) | | | | | | 1.05 |
| b | 221.6 | 0.88 | 0.73 | 0.54 | 138 | |
| c | 444.6 | 1.63 | 1.16 | 0.41 | 96 | |
| 55Cnc (3:1) | | | | | | 0.95 |
| b | 14.65 | 0.84 | 0.11 | 0.02 | 99 | |
| c | 44.26 | 0.21 | 0.24 | 0.34 | 61 | |
| d | 5360 | 4.05 | 5.9 | 0.16 | 201 | |

Table 2: Resonant orbits in exoplanetary systems.

the planet falling into the star. On the other hand the disc may help to create resonances (for example 2:1) as well. When the disc disappears the resonances will be modified.

I would like to investigate the effect of the disappearance of a disc for the orbits of planets. This may be especially important in case of resonant orbits. First I would like to use an approximate formula for the variation of the semimajor axis.

## Acknowledgments

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